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J. Hockley

S U M M A R Y

An understanding of the morphology of travelling ionospheric disturbances is essential to short-range high-frequency direction finding, particularly for systems employing vertical triangulation and dynamic tilt correction techniques. A variety of methods have been used in the past to study these disturbances, but to date little statistical information has been obtained on the extent to which they can be correlated in space.

In support of research in this area, a compact mobile H.F. doppler probe has been developed for deployment at spaced locations. Each of a group of such systems measures the apparent height of the local ionosphere and provides a doppler signature of overhead disturbances for later comparison and interpretation.

ABSTRACT

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In support of research in this area, a compact mobile H.F. doppler probe has been developed for deployment at spaced locations. Each of a group of such systems measures the apparent height of the local ionosphere and provides a doppler signature of overhead disturbances for later comparison and interpretation.

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1. INTRODUCTION

Current work in the field of ionospheric research includes the study of travelling ionospheric disturbances (TIDs) and ionospheric tilts, phenomena which are responsible for significant errors in short-range high frequency direction finders. It has been known for some years(ref.1) that fluctuations exist in the frequency of ionospherically reflected signals. These frequency deviations are attributed to changes in reflection height due to the passage of ionospheric irregularities such as TIDs. The fluctuations impose a frequency modulation on the reflected signal with deviations up to a few hertz, which can be considered as a doppler shift of the received signal.

Observations of ionospheric irregularities were made by Pierce and Mimno in 1940(ref.2) at which time they recorded large variations in the number of reflections of pulses from the F region. Since then a variety of instrumental techniques have been used by workers in this field(ref.3,4), and in more recent years the doppler method has been used with considerable success(ref.5,6).

The experiments conducted so far have used essentially fixed equipment installations resulting in inherent limitations on the extent of the information obtainable on TIDs. In particular, with the existing instrumentation it has not been possible to obtain statistical data on the extent to which TIDs and other disturbances can be correlated in space. An understanding of this parameter is essential to single station location (SSL) systems employing vertical triangulation(ref.7) and dynamic tilt correction techniques(ref.8).

There was, therefore, a need to provide a reliable method for determining the spatial correlation of TIDs. It was considered that this requirement could be satisfied by deploying three or four mobile equipments capable of timing and recording doppler signatures of overhead events for later comparison and interpretation.

Such a mobile equipment, DOPLATCH, has now been developed for rapid deployment at remote sites. Due to the constraints which mobility places on the design of such an equipment, considerable emphasis has been placed on simplicity of concept and ease of installation and operation. The DOPLATCH pulse transmitter and receiver are co-located in a caravan and share a small orthogonal delta array developed for the system. A technique for recovery of the doppler component is used which requires only one receiver and thus obviates the need for dual interconnected receivers as used in previous doppler experiments(ref.9,10). Doppler data, local time and apparent reflection height are recorded on punched paper tape for off-line computer processing.

This note describes the DOPLATCH equipment and briefly discusses the background to the requirement for such a system. The salient design features are covered in detail and future developments discussed.

2. PREVIOUS STUDIES USING THE H.F. DOPPLER TECHNIQUE

A doppler technique invented by Watts and Davies(ref.5) has been used since the early 1960's with the original purpose of recording and displaying the frequency of fading radio signals reflected at the ionosphere. It was soon realised that the technique had potential for studying the ionospheric effects of solar flares in the E and F regions. During the course of the investigations it became clear that, even in the absence of solar flares and magnetic disturbances, fluctuations were present in the frequency of ionospherically reflected signals, particularly from the F2 region. These frequency changes were attributed to the motion of irregularities which produce changes in the reflection height. It is now known that such ionospheric disturbances can be caused by a variety of infrasonic waves which fall into the generic classification of atmospheric waves having quasi-periods of the order of 5-60 min.

Some of the observed disturbances have been directly associated with earthquakes, nuclear explosions(ref.11) and possibly tropospheric storms. It is established that many ionospheric disturbances have auroral zone sources.

The instrumented technique used by Watts and Davies is illustrated in figure 1. The transmitter is driven by a highly stable crystal oscillator to ensure that carrier instabilities are much less than the doppler perturbations. This requires a stability of about 1 part in 10^8 and preferably an order of magnitude better. The receiving system comprised essentially of two interconnected receivers with common local oscillators to overcome problems of differential frequency drift between each receiver. The outputs from the signal channel, fed from the antenna, and the reference channel are compared in a phase-sensitive detector and the output recorded on magnetic tape moving at a speed of 1 in/min. Analysis of the tape recorded signal was performed at a play-back speed of 30 in/s by an audio spectrum analyser.

3. PROPOSALS FOR A MOBILE DOPPLER PROBE

Instrumentation based on the technique outlined above was considered as the basis of a mobile normal incidence doppler probe. However, the author felt that a considerable reduction in instrumental complexity could be achieved and suggested two alternative techniques each requiring the use of only one receiver.

The first method, which will be called the simultaneous injection method, gives the doppler component directly as output. The second, or sequential injection method, gives an output corresponding to the change with time of the phase path, the time derivative of which is the doppler component, i.e.

$$\Delta f = \frac{\Delta p}{\Delta t}$$

3.1 Simultaneous injection method

If two coherent sine waves, f_1 and f_2, of slightly differing frequency are applied to a suitable linear network, their instantaneous amplitudes may be added. The spectrum of the resultant waveform consists only of frequencies f_1 and f_2, i.e.

Let

$$y_1 = A \operatorname{Sin} 2\pi f_1 t$$

$$y_2 = A \operatorname{Sin} 2\pi f_2 t$$

then

$$y_1 + y_2 = A(\operatorname{Sin} 2\pi f_1 t + \operatorname{Sin} 2\pi f_2 t)$$

$$= 2A \operatorname{Sin} 2\pi\left(\frac{f_1 + f_2}{2}\right) t.\operatorname{Cos} 2\pi\left(\frac{f_1 - f_2}{2}\right)$$

This is equivalent to a sine wave of frequency $\frac{f_1 + f_2}{2}$ varying cosinusoidally in amplitude from +2A through 0 to -2A and back with a frequency of $\frac{f_1 - f_2}{2}$. Figure 2 shows that if the absolute amplitude of the waveform is considered, the increase and decrease occurs at a fundamental

frequency of (f_1 - f_2) which is the beat frequency. This principle is used in the simultaneous injection method where a coherent reference frequency derived from the transmitter drive oscillator is offset by a small amount and added to the ionospherically reflected pulses containing a doppler component. The beat, or modulating, envelope of the resultant waveform (f_1 - f_2 $\pm\Delta f$) where Δf is the instantaneous deviation frequency, therefore contains the offset frequency plus a doppler component.

The offset frequency is necessary to determine the sense, positive or negative, of the doppler frequency component; it has to be greater than the largest expected negative doppler excursion to avoid frequency 'fold back'. A single channel receiver is used to process the composite signals.

3.2 Sequential injection method

The time-of-flight to the first return of a transmitted radio pulse via the F2 region is typically of the order of 2 ms. This provides a convenient window between transmit and receive in which to inject a frequency-offset sample of the transmitted pulse just prior to the arrival of the returned pulse of interest. This train of pulses comprising reference first and second returns etc., is processed sequentially through a single-channel receiver. At I.F. the pulse train is split into two sub-channels with a delay element inserted in one sub-channel equal to the time difference between the reference and returned pulse. If the two sub-channels are then re-combined, the reference pulse of one sub-channel will be coincident in time with the ionospherically reflected pulse in the other sub-channel. At the appropriate time the two channels are gated into a phase comparator.

As the two pulses are coherently derived, any changes with time of the carrier phase (other than that produced by the fixed frequency offset) within the pulse period will be due to changes in propagation phase-path. The time differential of this phase-change will provide the doppler component. The pulse sequence diagram figure 3 and block diagram figure 4 illustrates the sequential injection method.

4. GENERAL SYSTEM DESCRIPTION

For reasons of simplicity of concept and ease of implementation, the simultaneous injection method was chosen as the basis of the DOPLATCH system. DOPLATCH is a frequency coherent system, the reference signal and control waveforms being derived from the transmitter crystal oscillator. This reduces problems due to oscillator frequency drifts and has the advantage of not requiring the highly stable crystal oscillators which were necessary with previous HF doppler systems. Although doppler variations from ionospheric reflections of greater than about 2 Hz are unusual, the offset frequency of DOPLATCH is set at 5 Hz. This ensures that doppler variations about the centre-frequency of the phase-locked-loop, used in the demodulation process, are within the tracking range of the device.

The pulse transmitter, receiver and all demodulation and recording equipments are co-located in a 15 ft caravan. A small orthogonal delta array, which was developed for the system, is shared by the transmitter and receiver by means of a passive isolation unit. Provision is made for reception of either the ordinary or extraordinary downcoming wave. During transmission the array is linearly polarised. The equipment is designed to operate on three allocated frequencies of 6.7155 MHz, 5.38 MHz and 3.84 MHz, all of which are derived from the transmitter exciter unit. The equipment will operate at other frequencies in the H.F. band by changing to an appropriate divider module.

The caravan provides sufficient amenities such as cooking, water, food storage and air conditioning to allow the system to be operated for extended periods in remote locations. The main components of the complete system are shown in figure 5.

5. DETAILED SYSTEM DESCRIPTION

This section briefly describes the basic functions of the various components comprising the system.

5.1 Transmitter

DOPLATCH was designed to be compatible with an existing H.F. beacon transmitter of local manufacture(ref.11) comprising three main units:

(a) pulse exciter type 7404 to provide all control functions, frequencies, operating modes, pulse lengths and timing,

(b) linear power amplifier type 7010G with an operating frequency range of 2-12 MHz, a CW power output of 250 W and pulse power of 1 kW, and

(c) power supply unit.

With DOPLATCH, the transmitter is always used in the pulse mode at a P.R.F. of 50 Hz and generally a pulse width of 300 μs.
Additional circuitry was required in the transmitter exciter to eliminate a residual carrier signal in the interpulse period. Such a residual carrier, when amplified by the power amplifier stages and the gain of the receiver, was sufficient to mask any ionospherically returned signals.

5.2 Common transmit/receive antenna

The main requirements of the antenna are:

(a) to have a substantially vertical directivity,

(b) to provide the transmitter with a load of better than 2:1 SWR over the required frequency range,

(c) to be compact and simple to erect, and

(d) to be capable of providing, with suitable external phasing circuitry, left or right circular polarisation on receive and linear polarisation on transmit.

An orthogonal delta arrangement fulfils the above requirements and such an antenna was developed with reference to published data(ref.13,14) describing simple, single-plane, multi-wire delta antennas.
For transmitting purposes, the physical height of such an antenna is primarily determined by its lowest operating frequency. To maintain an acceptable SWR at 3.84 MHz (lowest allocated frequency for DOPLATCH) requires an antenna with sloping elements of not less than about 10 m length.
The method employed of array sharing for transmit and receive with polarisation diversity incurs attenuation prior to the receiver. Figure 6 shows the distribution of losses in the pre-receiver stages and gives a measured loss of 9 dB overall. However, a standard insertion-loss measurement is not a true representation of normal conditions where a $\pi/2$ phase relationship exists between signals from each half of the array. Consequently such a measurement will result in an addition 3 dB loss being recorded as the test signal is equally divided between the sum and difference outputs of the quadrature hybrid. In practice, the selected 'O' or 'X' component of the signal incident on the array will suffer a total loss of only 6 dB in the pre-receiver stages, the unwanted component being dissipated in the switchable 50 Ω load.
A typical noise figure for a Racal 117 is around 7 dB to 9 dB. If, therefore, we assume a receiver noise figure of 8 dB, then the additional 6 dB input loss, excluding the array, gives an overall system noise figure of 14 dB, which is just adequate to maintain an externally noise limited system. This assertion is based on the expected values of atmospheric noise in the lower H.F. band for South Australia(ref.15) and neglects man-made and galactic noise sources.

For performance comparison purposes, an orthogonal delta array with support mast of 11 m and another scaled-down version with an eight metre mast were constructed. A subjective assessment of their relative performance with DOPLATCH was made by alternately switching between the arrays. After taking account of the lower signal pick-up from the smaller array it was judged that from signal/noise ratio considerations, there was no perceptible difference in performance between them. As there are considerable practical advantages in keeping the array as compact as possible, the smaller array was chosen for use with DOPLATCH. The photographs and drawings, figure 7, give construction details and admittance plots are presented in figure 8.

The support mast is 50 mm diameter aluminium tube in three sections. Each sloping element is of three-wire construction with varying spacing to reduce impedance changes over the frequency range. 600 Ω non-reactive loads, located at the mast-head, terminate the two deltas and 600/50 Ω high-power baluns, clamped to the lower part of the mast, provide impedance transformation to the two 50 m co-axial feeders back to the caravan.

5.3 Transmit/receiver isolation unit

Considerable isolation of the receiver from the transmitter output is achieved by using an arrangement of three interconnected, high-power, three-port hybrid transformers. The effectiveness of this arrangement is critically dependant upon the 'opposite-port' isolation of each hybrid unit, which in turn relies upon careful construction and interconnection of the transformers. Non-inductive, high-power terminating and ballast resistors are used in the complete assembly. Each hybrid has windings of copper tape interleaved with Mylar insulation and wound onto a pair of FX1105 ferrite cores. When connected to the antenna the assembly provides isolation of the transmitter to the receiver of better than 35 dB but the method incurs a transmission and reception loss of 3 dB. Construction details are shown in figure 9(a) and (b).

5.4 Secondary receiver protection

Typically, the osolation unit reduces the transmitted pulse to a level of about 5 V r.m.s. at the receiver. During transmission additional protection for the receiver is provided in the form of a self-terminating R.F. change-over diode switch in addition to receiver blanking. Circuit details of the switch are given in figure 9(c).

5.5 'O' and 'X' ray discrimination

For reception, a quadrature hybrid is used to produce left and right circular polarization of the array giving discrimination against either the 'O' or 'X' returned ray. Figure 10 is an attempt to show vectorially how this is achieved in conjunction with the quadrature outputs from the array.

A self terminating manual changeover switch selects either the 'O' or the 'X' output and combines this with the reference signal in a directional coupler. The combined signals provide input for the receiver.

The 'O', 'X' selection switch has a dual function, the second of which is to register a flag on thepunched output tape to record which mode is being received. The flag is used to select an appropriate symbol when computer printing the doppler signature so that changes between 'O' and 'X' modes are recorded as part of the signature.

5.6 Receiver

The problem of signal break-through via direct radiation, earth-loops etc., from a transmitter into a co-located receiver has been successfully dealt with in a previous project(ref.16). The method involves biassing-off the first R.F. and second I.F. amplifiers of a Racal receiver some 60 μs before

arrival and for the duration of the pulse transmission. This prevents ringing in the I.F. filters which would otherwise obscure early ionospheric returns such as from the E region. This blanking modification is incorporated into the Racal 117 receiver used in the DOPLATCH system.

5.7 Frequency divider

As mentioned previously, DOPLATCH is a frequency coherent system, all reference and control frequencies being derived from the transmitter crystal oscillators. Three divider chains, appropriate to the three transmitter frequencies, each provide a 50 Hz output for synchronisation of transmitter pulsing with receiver blanking, clock drive and generation of sampling intervals. A further division to 5 Hz provides the offset frequency used in the derivation of the reference signal.

As the P.R.F. is derived from the crystal oscillator a problem could arise, when using a number of spaced DOPLATCH equipments, due to relative drift of the signals from each station. This would cause corruption of the data if the remote and local pulse returns became coincident. To avoid this situation, a switch is provided to enable the P.R.F. to be locked to the mains frequency thus maintaining a constant spacing between returned pulses from the network of stations.

5.8 Reference signal generator

The offset of 5 Hz between the reference and signal frequencies is achieved by the phase-shift method of SSB generation. This method relies on the fact that the upper and lower sideband of an A.M. signal differ in their phase angles. Phase discrimination may thus be used to cancel one sideband of a double sideband system.

Consider the following DSB output where the modulating signal f(t) is a pure cosine wave.

$$fd_1(t) = \mathrm{Cos}\,\omega mt\,\mathrm{Cos}\,\omega ct = 1/2[\mathrm{Cos}(\omega c + \omega m)t + \mathrm{Cos}(\omega c - \omega m)t]$$

where $\mathrm{Cos}\,\omega mt$ is the modulating signal
and $\mathrm{Cos}\,\omega ct$ is the carrier

A SSB signal would have the simple form $\mathrm{Cos}(\omega c - \omega m)t$ and implies that we must add to the above expression an expression of the form

$$fd_2(t) = 1/2[\mathrm{Cos}(\omega c - \omega m)t - \mathrm{Cos}(\omega c + \omega m)t] = \mathrm{Sin}\,\omega mt\,\mathrm{Sin}\,\omega ct$$

upon adding, the upper sidebands cancel leaving the lower sideband

$$\mathrm{Cos}(\omega c - \omega m)t$$

This indicates that two modulating networks in quadrature are required, their outputs being summed by an adding network. Figure 11 illustrates the circuit arrangement.

5.9 Doppler detection

The 100 kHz receiver I.F. is displayed on an oscilloscope and a bright-up strobe, which is coincident with a pulse of reference signal, is aligned on the return of interest. The instantaneous addition of the reference and signal will produce a series of pulses at 50 Hz P.R.F. successively modulated in amplitude at a frequency of 5 Hz ± a doppler component. It is necessary to reconstruct the envelope of the modulating signal in order to extract the doppler component. After detection at I.F., a sample-and-hold

device stores the instantaneous amplitude of each pulse, thus producing a staircase waveform which is then filtered to reproduce a quasi-sinusoid corresponding to the original modulation envelope.

A phase-locked-loop, used as a tracking filter, removes the 5 Hz component from the reconstructed envelope leaving the doppler component as output. Figure 12 is a simplified block diagram of the process.

5.10 Digital doppler measurement

The tracking filter VCO centre frequency is 500 Hz, enabling measurement of the 5 Hz difference frequency to be made to a resolution of 0.01 Hz. This is accomplished by digitally sampling the VCO frequency over precisely measured one second intervals, the doppler component appearing as deviations about the centre frequency.

5.11 Measurement of apparent height

A narrow pulse transmitted vertically via the ionosphere will be received by its various modes of propagation separated in time. For a network of spaced systems monitoring TID's it is essential that each is probing the same region of the ionosphere. A measure of the apparent height of the reflection point at each station is achieved by counting a 150 kHz crystal controlled clock for the period of propagation of the R.F. pulse until the required return, thus giving a recorded height in kilometres.

6. OPERATING PROCEDURE

DOPLATCH is essentially a very simple piece of equipment to operate and merely requires the alignment and approximate amplitude adjustment of a moveable reference pulse to coincide with the received signal pulse. The receiver I.F. is displayed on an oscilloscope as an 'A' scan, figure 13 is a typical example of such a display. The brightened reference pulse is moveable on the display by means of a multi-turn potentiometer. It is aligned with the returned signal and immediately combines to produce a single pulse varying in amplitude at a rate of fo $\pm \Delta f$. Occasional adjustment of the reference position is required to follow movements due to slow changes in reflection height. Doppler, apparent reflection height, time and 'O' or 'X' mode of reception are automatically recorded on punched paper tape at a rate which is adjustable from one sample every two seconds thence by binary integer steps to once in 64 s. The tape format is shown in figure 14.

7. SIMULATED DOPPLER CHECKS

Two test arrangements were devised to check the accuracy of the complete DOPLATCH receiving systems. Figure 15(a) shows the general test set-up which comprises two synthesizers driven from a common, stable frequency standard to provide frequency coherent inputs.

In the first test, both the signal input and the reference input were provided by the synthesizers. By varying the frequency of one input in small, known steps, the tracking accuracy of the system could be precisely measured. The plotted results, figure 15(b), show almost exact agreement with the input conditions but as the resolution of the system is limited to 0.01 Hz, changes of that order will not be accurately digitized. Response of the tracking filter to changes as small as 0.001 Hz at around 7 MHz have been observed during bench checks but it was considered that recording to accuraces of better than ± 0.01 Hz was unnecessary for the proposed application.

The second test differed from the first in that the reference frequency is generated within DOPLATCH. One synthesizer input corresponds to fs (figure 5) and the other synthesizer input to fs $\pm \Delta f$.

8. FIELD TRIAL

A field trial to record doppler data on a single, unproven system would give no indication that the instrument was necessarily responding correctly to movements in the ionosphere, as there would be no independant or absolute check. A trial was therefore mounted to compare DOPLATCH with another system named FINGER LANCE(ref.16). Each system measures the doppler component by completely different methods, so that, if the signatures obtained from each, whilst simultaneously monitoring the same part of the ionosphere, showed very close correlation, then this, together with the simulated doppler tests, would give sufficient confidence that each of the systems was functioning correctly.

The results of a comparison trial are shown in figure 16. The FINGER LANCE data was consistently more damped in amplitude (doppler excursion) compared with DOPLATCH; this was particularly noticeable with the former on a sample count of 2^8. The problem was subsequently found to be due to a design fault in the FINGER LANCE equipment and will be rectified. Apart from this difference, a computer analysis of the two signatures gave a correlation coefficient of 0.996.

9. FURTHER DEVELOPMENT

Local performance tests and a week's trial observing TID's at a remote site, as part of a larger experiment involving other ionospheric measuring systems, have demonstrated the usefulness of DOPLATCH for its intended purpose. As a result, it is proposed to manufacture in the near future three more systems based on the prototype described. Three spaced stations will be sufficient to provide information on the direction of travel and spatial properties of TID's and a fourth station, perhaps provided by FINGER LANCE, will give some redundancy within the network of stations.

9.1 Reduction of equipment bulk

As the beacon transmitter occupies considerable space within the DOPLATCH caravan, a useful reduction in total bulk and weight of the equipment could be effected by replacing this transmitter with a smaller, simpler unit. Such a transmitter with a pulse power output of 5 kW has already been incorporated as part of the new Ionosonde 4A developed in Australia by the Ionospheric Prediction Service(ref.17). This transmitter should be admirably suited for use with the DOPLATCH system. With some rearrangement of the units within the receiving rack, the transmitter and passive isolation unit could be conveniently located in the same rack, with the further advantage of eliminating the present inter-rack cabling. The resulting compact system probably represents the optimum development of the DOPLATCH system in terms of cost effectiveness and portability.

9.2 Development for possible future roles of DOPLATCH

Looking beyond the current experiments to determine the spatial correlation of TID's, it is interesting to consider the feasibility, using an array of DOPLATCH equipments, of locating the sources of individual travelling disturbances by a long base-line direction finding technique. As disturbances can travel at speeds within the range 100 to 500 m/s, a two-dimensional array of probes, extending over several hundred kilometres, would be required to determine the velocity vector. There are many possible array configurations, each requiring about six or eight mobile normal incidence probes. For experiments of this type requiring more than, say, four probes, there would be considerable advantages in terms of cost, in further development of the DOPLATCH hardware, resulting in a complete equipment capable of being transported by an average sized station-sedan. This additional development would be directed towards providing a dedicated

receiver and composite transmitter drive/receiver local-oscillator synthesizer. As the system is required to operate at only three allocated frequencies, a dedicated receiver would be a relatively cheap and simple unit to build. Likewise the frequency synthesizer would be of basic design requiring few components. The two stages of refinement which logically follow the prototype stage are illustrated in figure 17 and a basic block diagram for the final suggestion is given in figure 18.

9.3 Improvements to Delta array

The present mast supporting the orthogonal delta array is raised to the vertical position by means of a goose-neck secured to the ground. There are practical difficulties involved with this method of erection as considerable stress is placed on the mast and also the guys and array elements can become entangled during the process. It is planned, therefore, to replace the existing mast with one of the pneumatic telescopic type with a closed length of about six feet. This allows the mast to be secured in the vertical position and all intermediate guys and array elements to be attached before elevating to its full height.

10. CONDLUDING REMARKS

The requirement for recording signatures of the overhead ionosphere at several spaced locations has been provided by the DOPLATCH equipment. The concept and design of the equipment reflects the constraints imposed by the need for a compact, self contained and easily deployed system which is simple to operate. Field tests have demonstrated its effectiveness in providing doppler data even under conditions of rapidly fading ionospheric returns.

There is scope for development of the prototype system where further reduction in total equipment bulk is deemed desirable. It is possible that the broadband shared transmit receive array developed for the equipment will have useful application for short-range, H.F. skywave communications systems.

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15		"World Distribution and Characteristics of Atmospheric Radio Noise". C.C.I.R. Report No.322, 1963
16	Spragg, R.D.	"Finger Lance: A Semi-Automatic H.F. Direction of Arrival and Doppler Measuring System for the Study of Local Travelling Ionospheric Disturbances". WRE-TN-A243 (AP), March 1974
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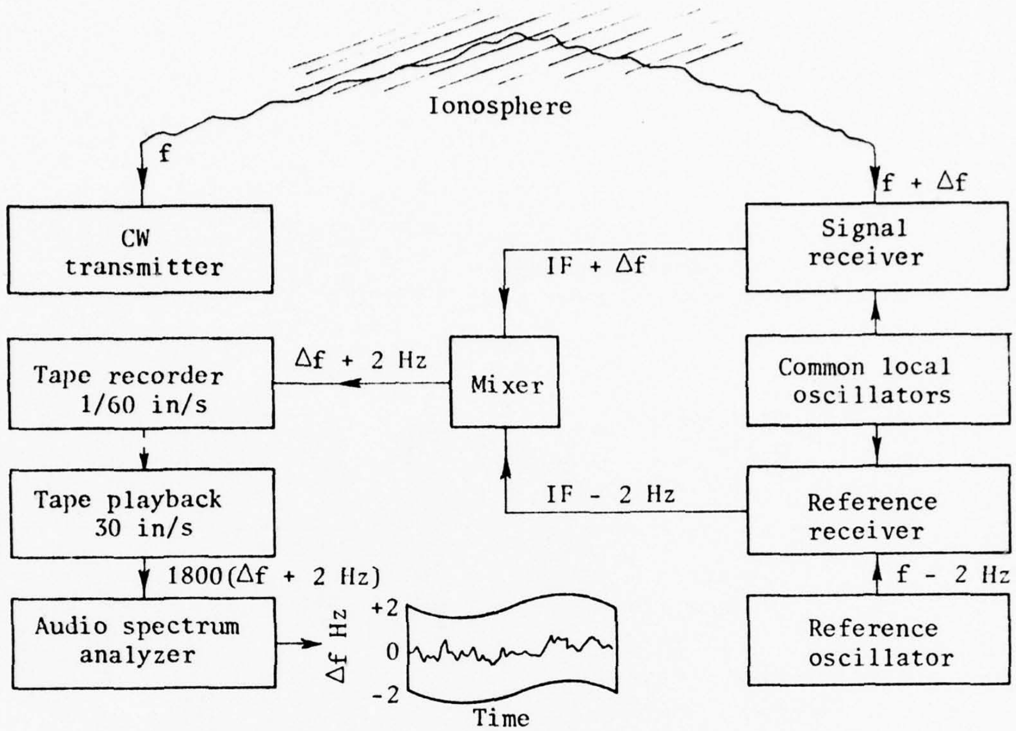
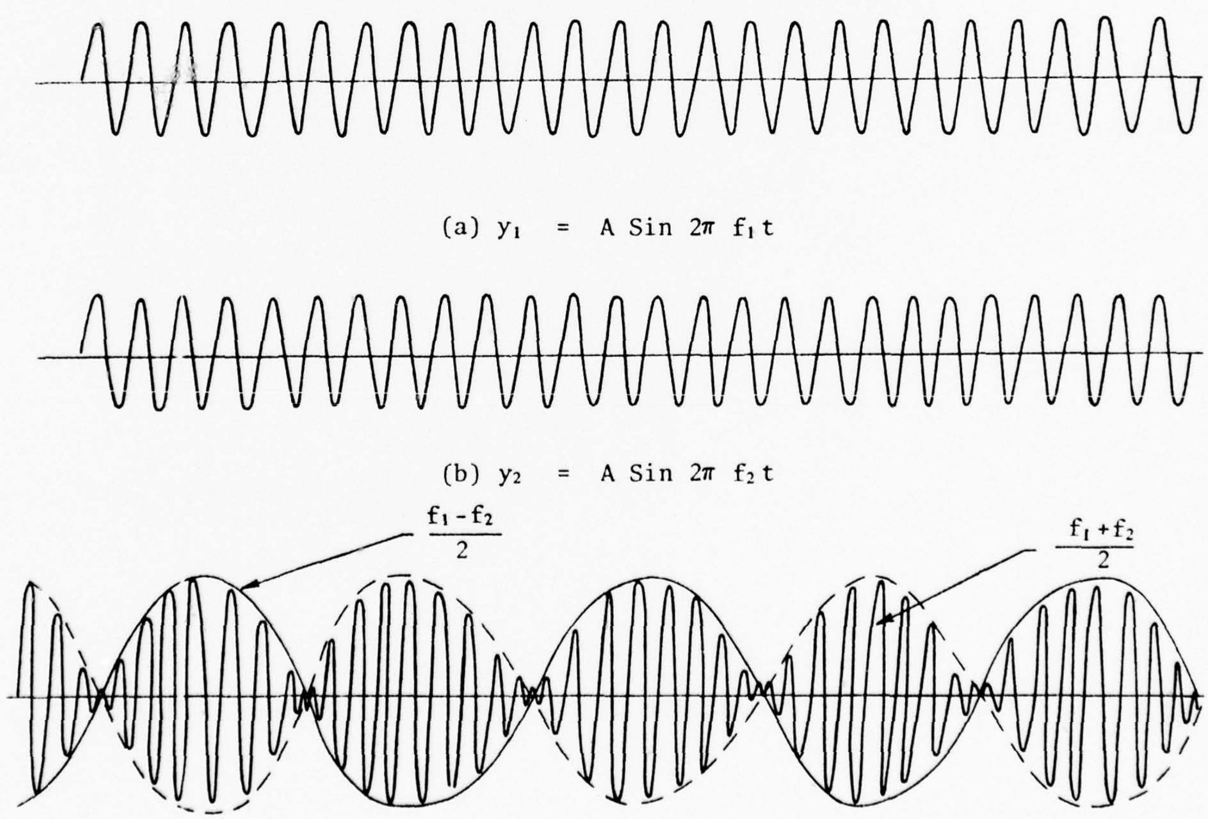


Figure 1. Block diagram of typical doppler system



(a) $y_1 = A \sin 2\pi f_1 t$

(b) $y_2 = A \sin 2\pi f_2 t$

(c) $y_1 + y_2 = 2A \sin 2\pi \left(\frac{f_1 + f_2}{2}\right) t \,.\, \cos 2\pi \left(\frac{f_1 - f_2}{2}\right) t$

Figure 2. Addition of two sine waves of equal amplitude

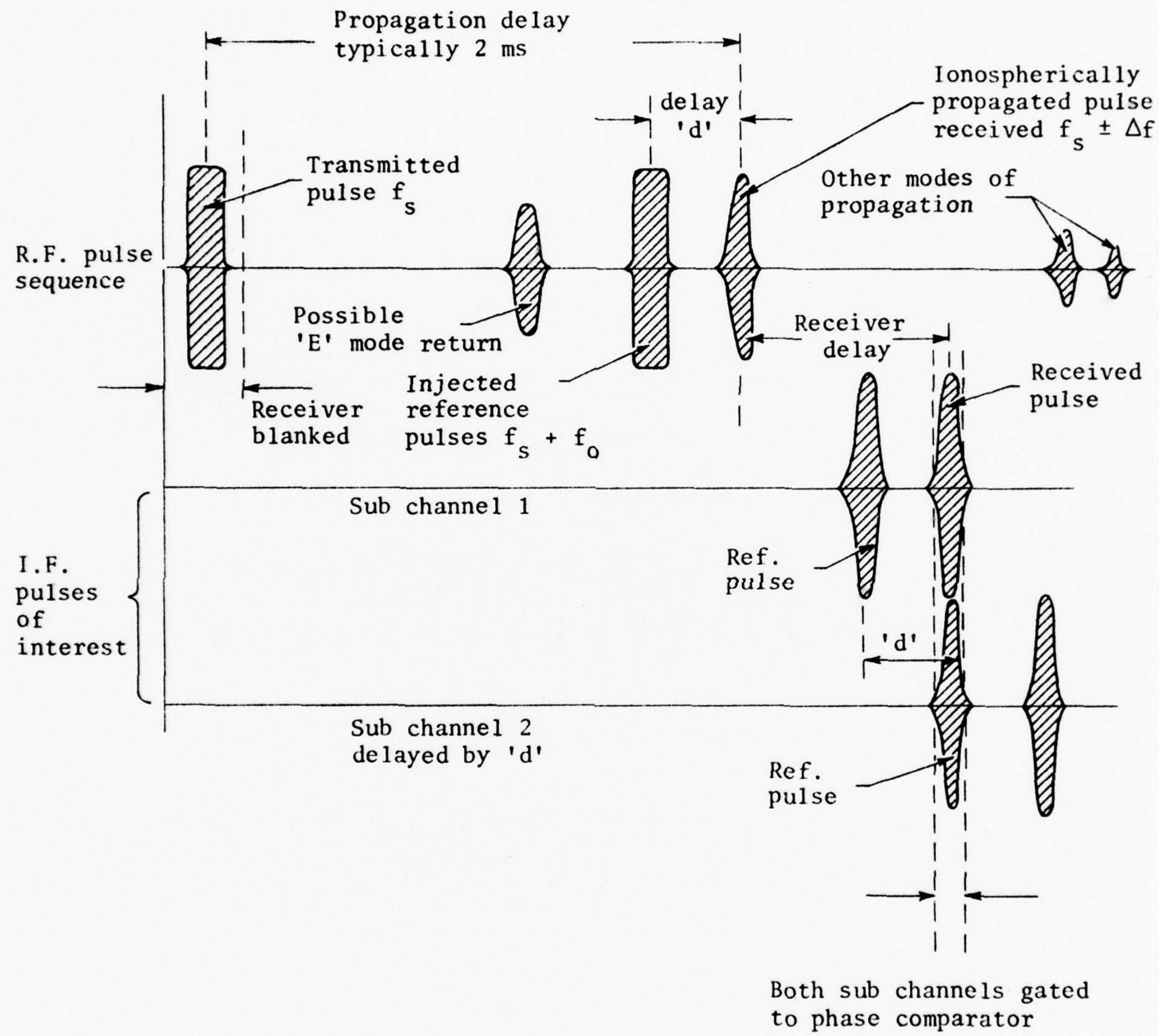


Figure 3. Sequential injection, pulse diagram

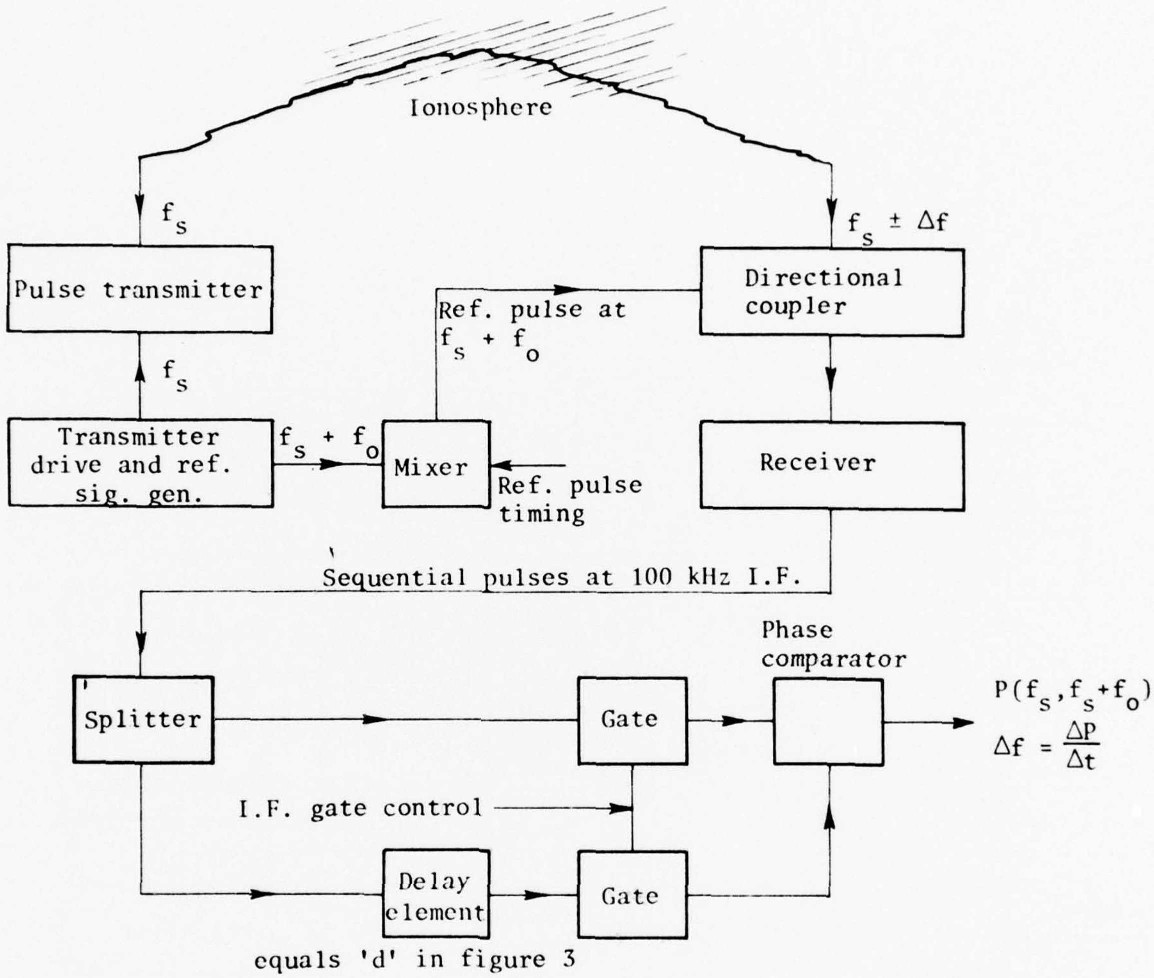


Figure 4. Sequential injection, basic block diagram

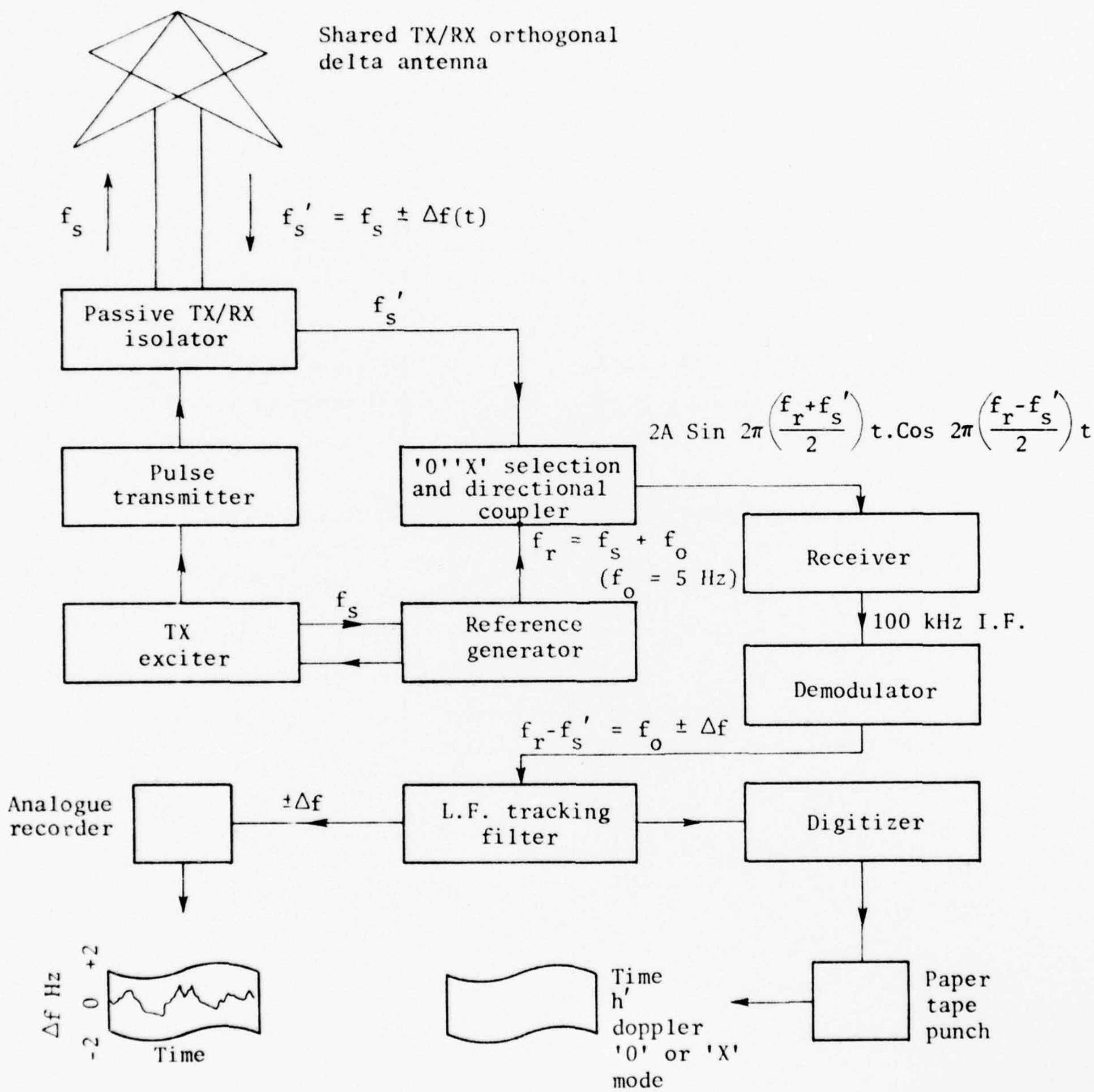


Figure 5. Block diagram of doplatch system

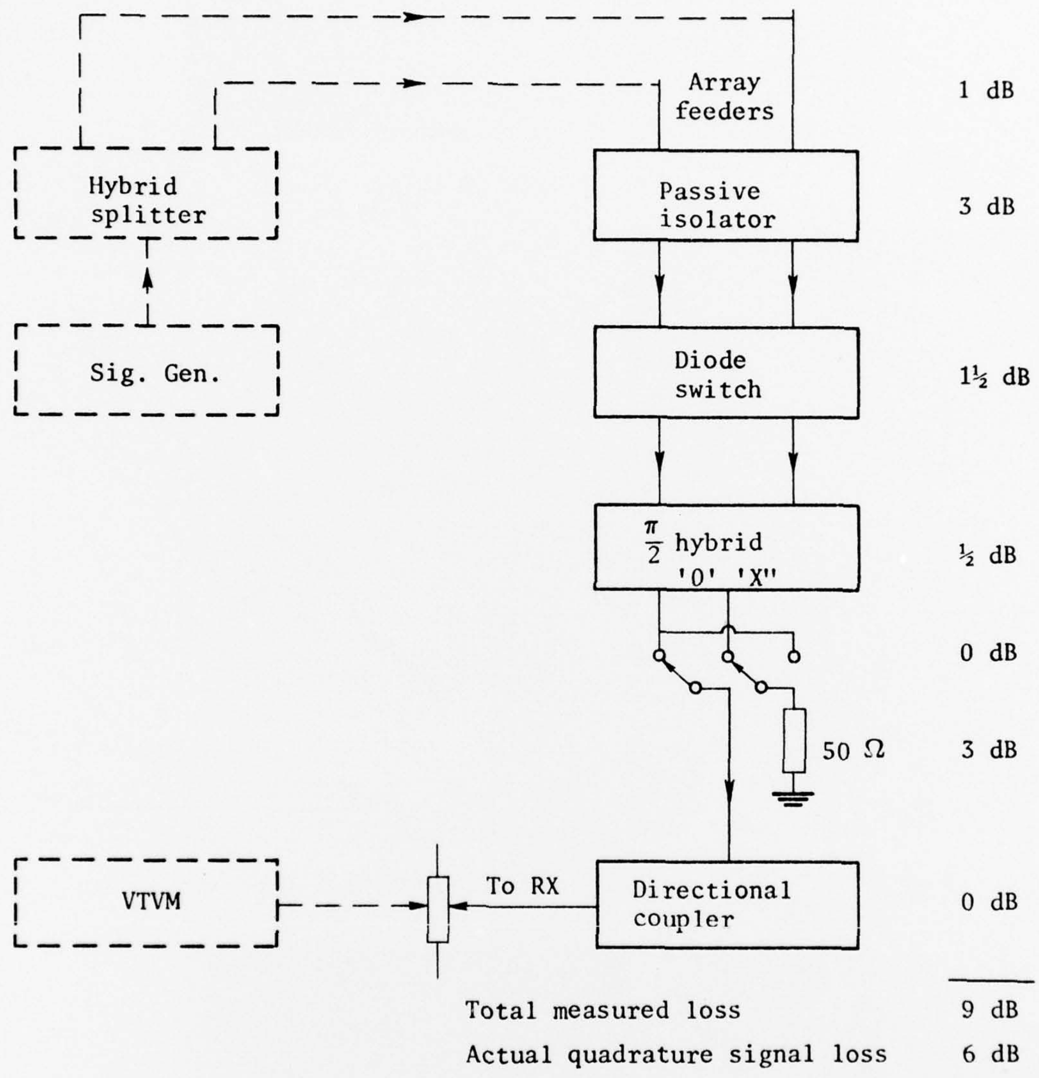
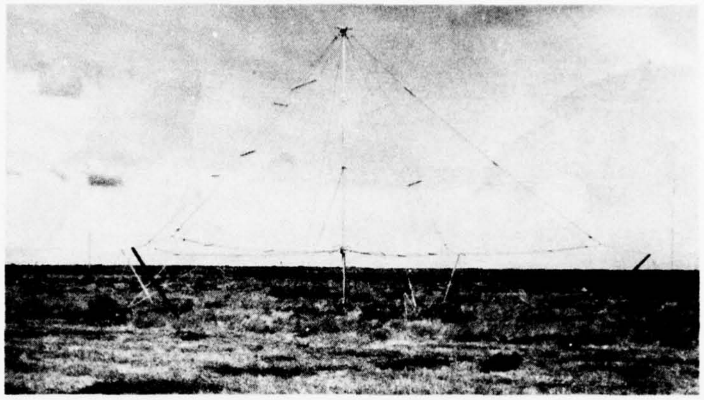
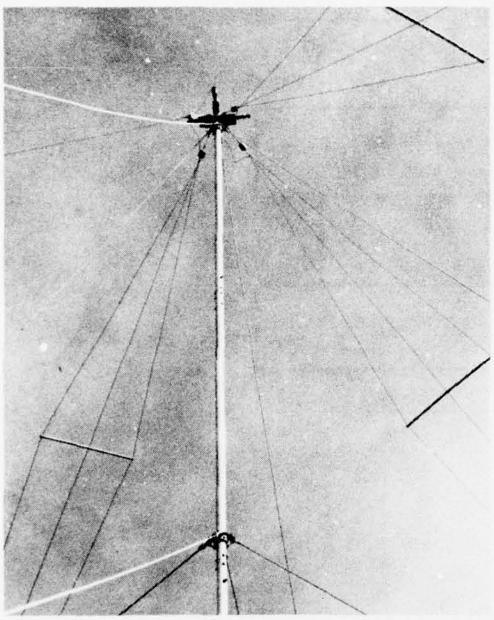


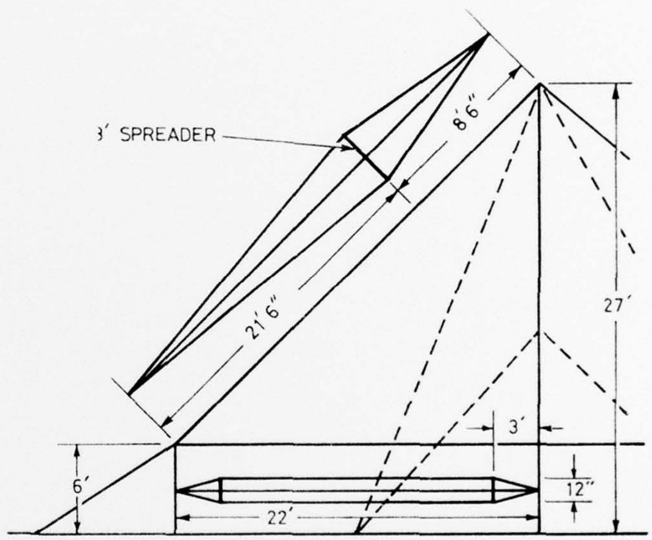
Figure 6. Measurement of losses in pre-receiver stages



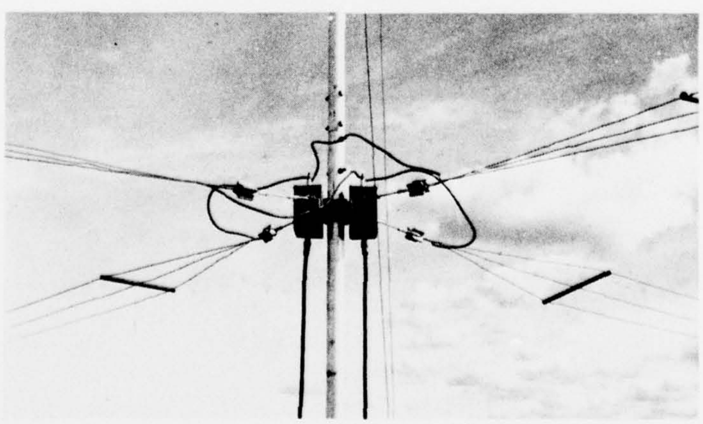
General view of array



Sloping elements and terminating resistors



Principal array dimensions



Detail of 3-wire transmission lines and baluns

Figure 7. Details of 8 m high orthogonal delta array

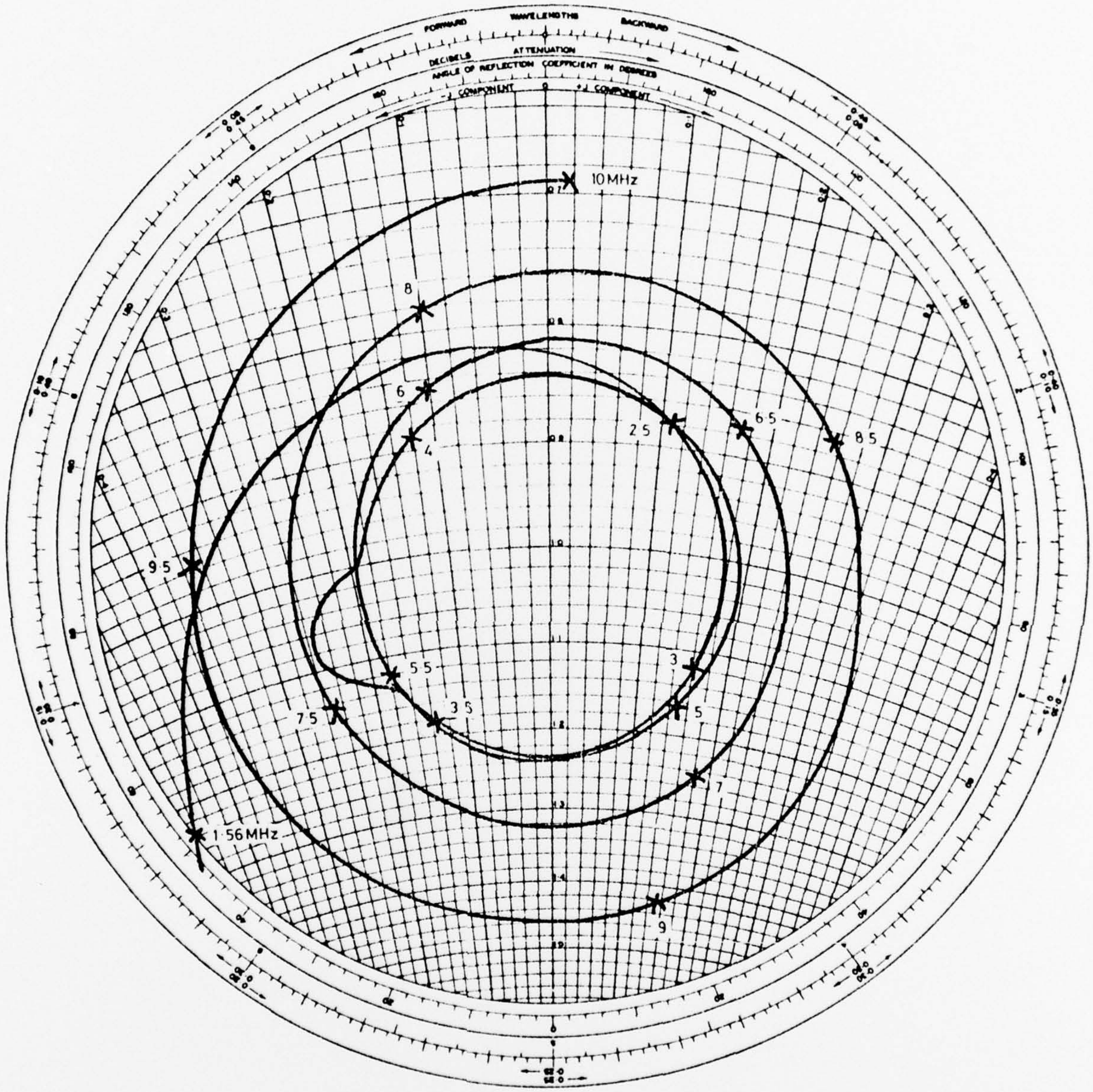


Figure 8(a). Admittance of 50 m feeder terminated by Balun and Delta antenna, normalised to 20 m/mho

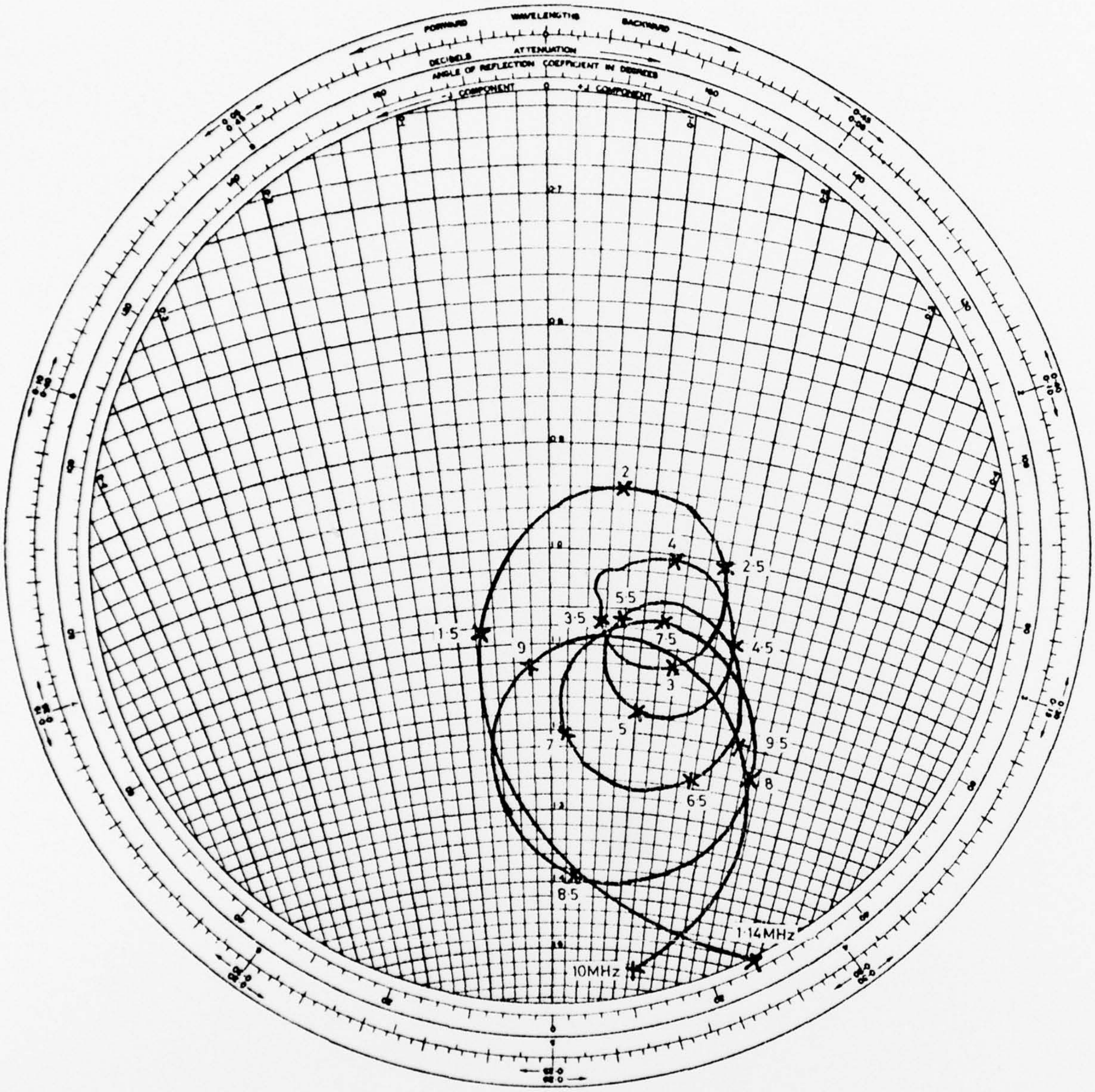
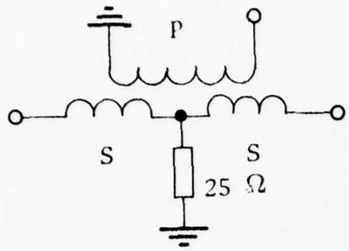


Figure 8(b). Admittance presented to transmitter by isolator unit terminated by orthogonal Delta, normalised to 20 m/mho



Turns ratio.	$\sqrt{2}$:1+1
Core.	Mullard F x 1105 'E' cores
Windings.	Pri 5t. 0.5 in x 0.005 in Cu tape centre start (contra-wound)
Ballast resistor.	Welwyn metox power oxide
Insulation.	0.005 in mylar.

Figure 9(a). High-power hybrid transformer details

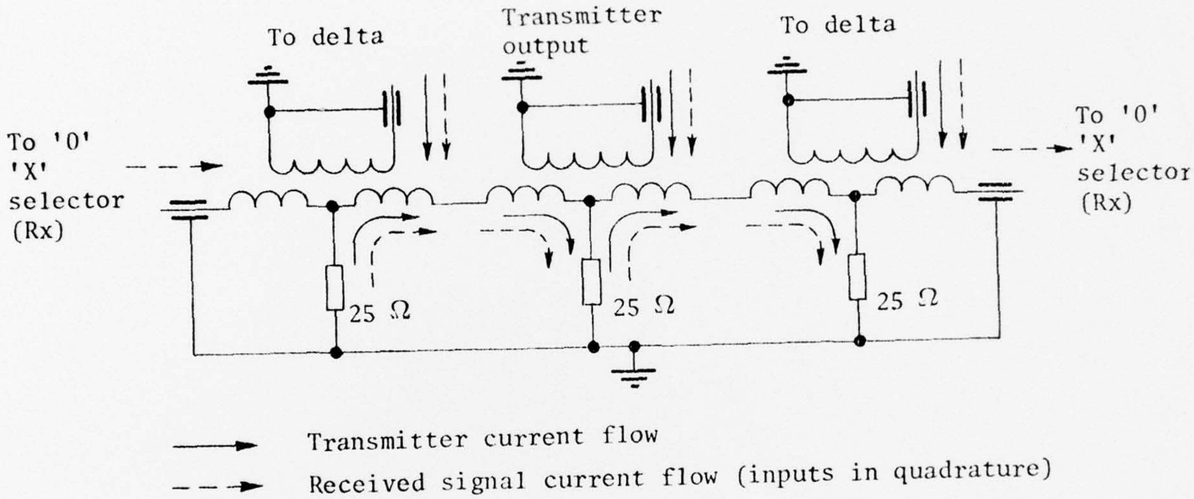


Figure 9(b). Passive isolator comprising 3 high-power hybrid units

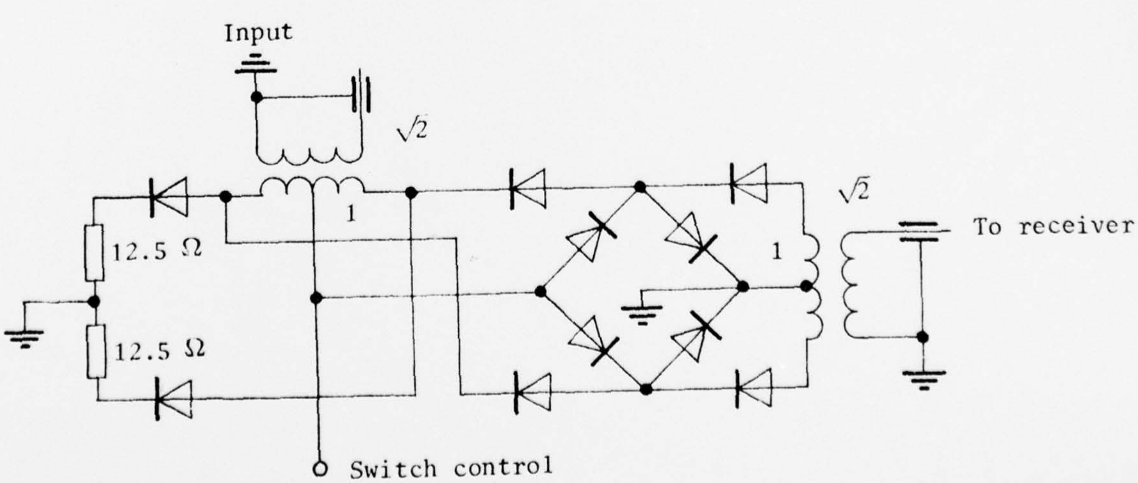
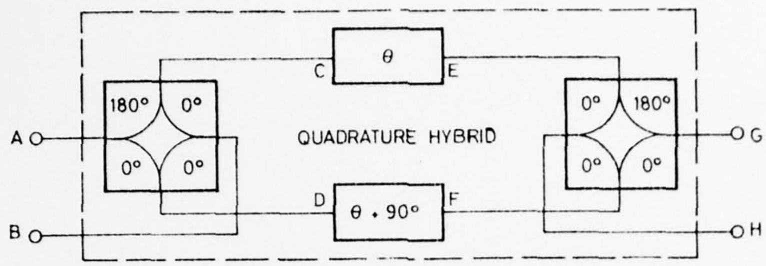
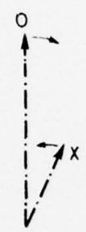


Figure 9(c). Self-terminating changeover switch

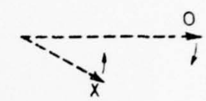
(1) For simplicity let $\theta = 0^{o}$
(2) The contra-rotating vectors are arbitrarily anotated '0' and 'X'



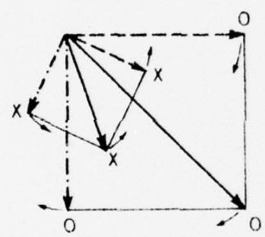
(a) Input to 'A' from one arm of array



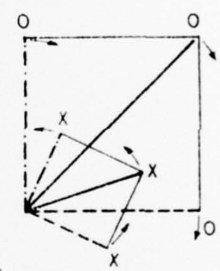
(b) Input to 'B' from quadrature arm of array



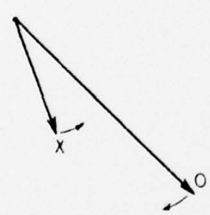
(c) Addition of A and B at C



(d) Addition of A and B at D

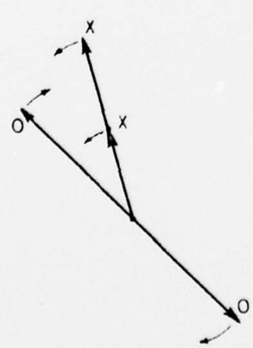


(e) No phase-shift of C at E



(f) 90^{o} phase-shift of D at F

(g) Addition of E and F at G. '0' cancels 'X' is O/P



(h) Addition of E and F at H. '0' is O/P 'X' cancels

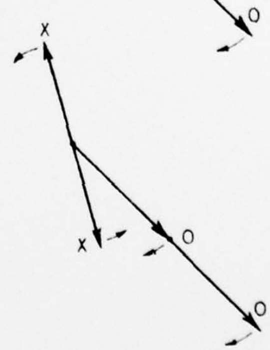


Figure 10. '0', 'X' ray separation

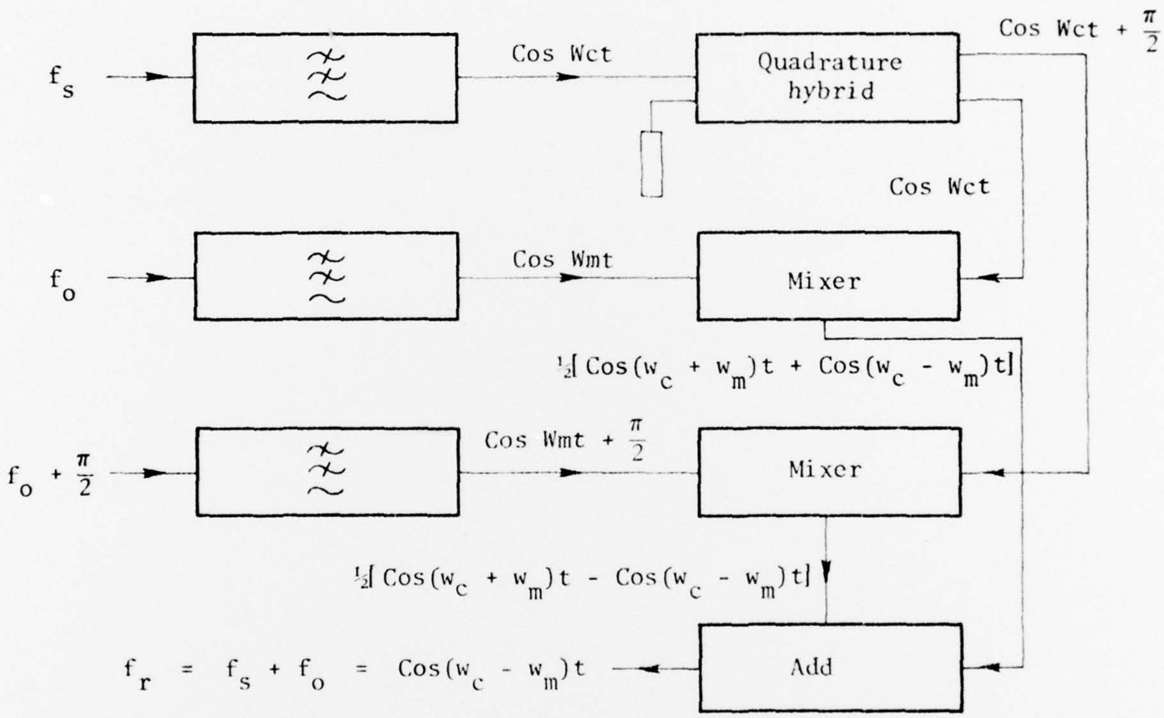


Figure 11. Reference frequency generation

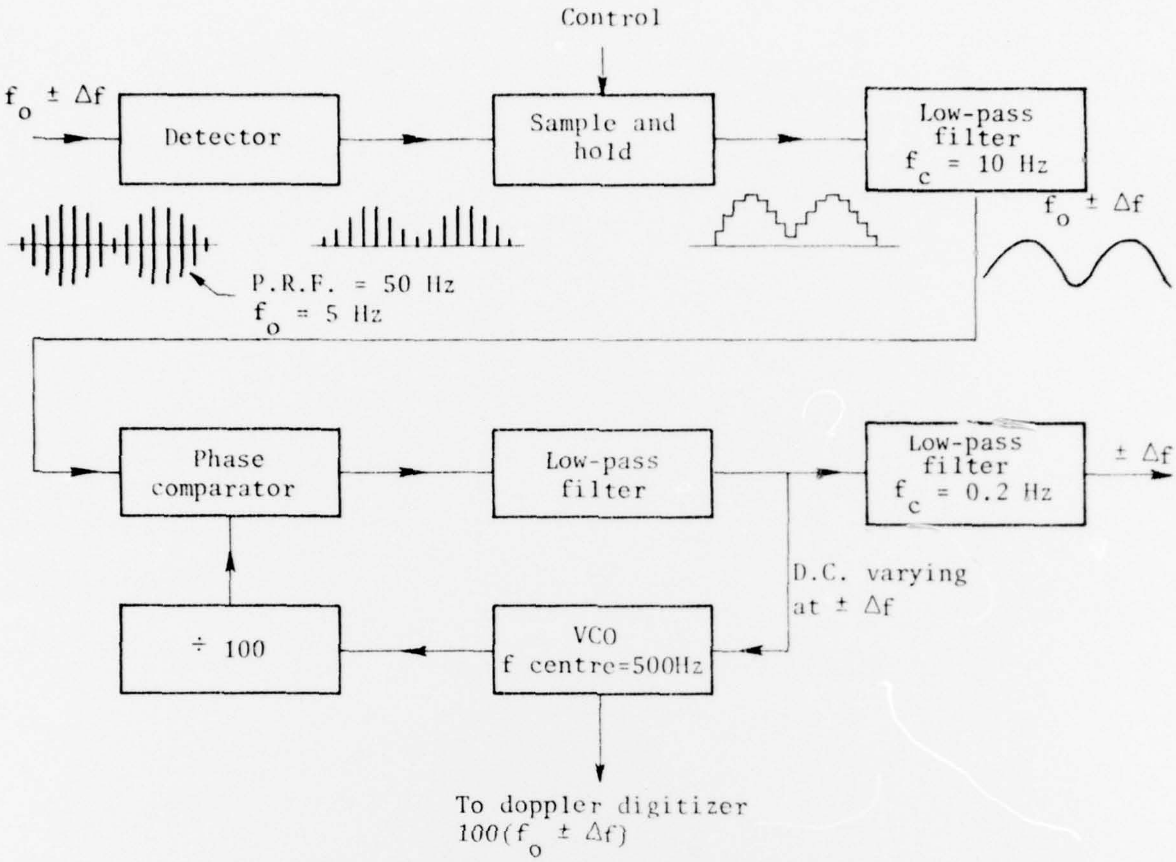


Figure 12. Simplified block diagram of doppler detection

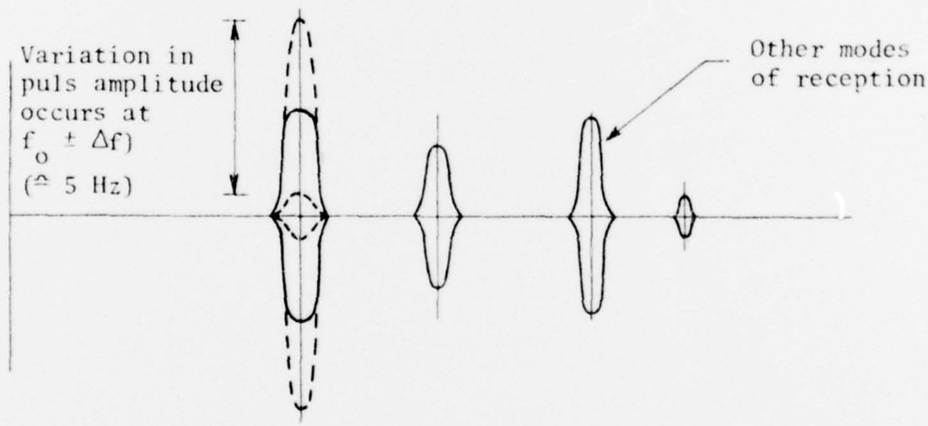


Figure 13. Typical 'A' display

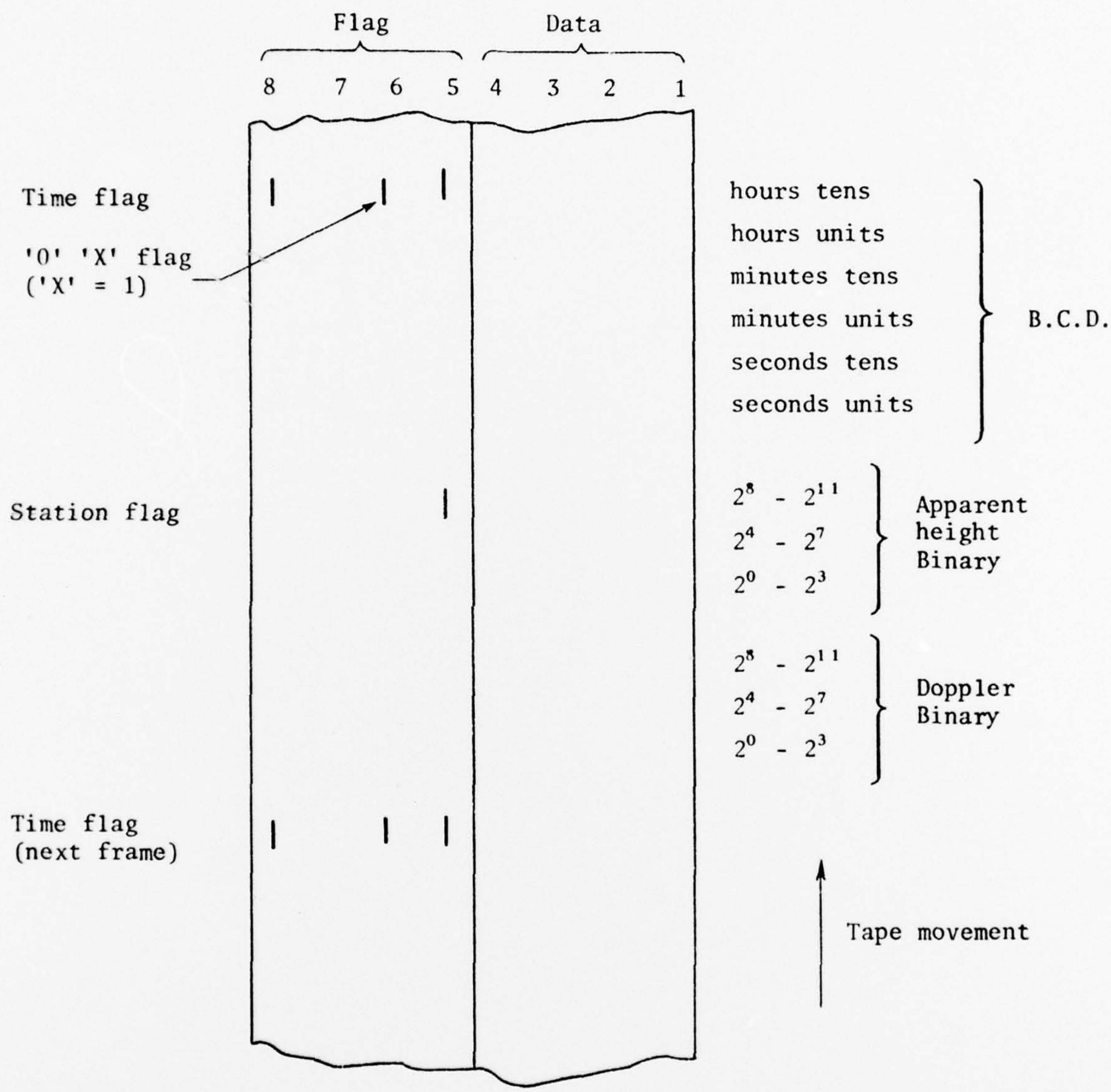


Figure 14. Paper tape format

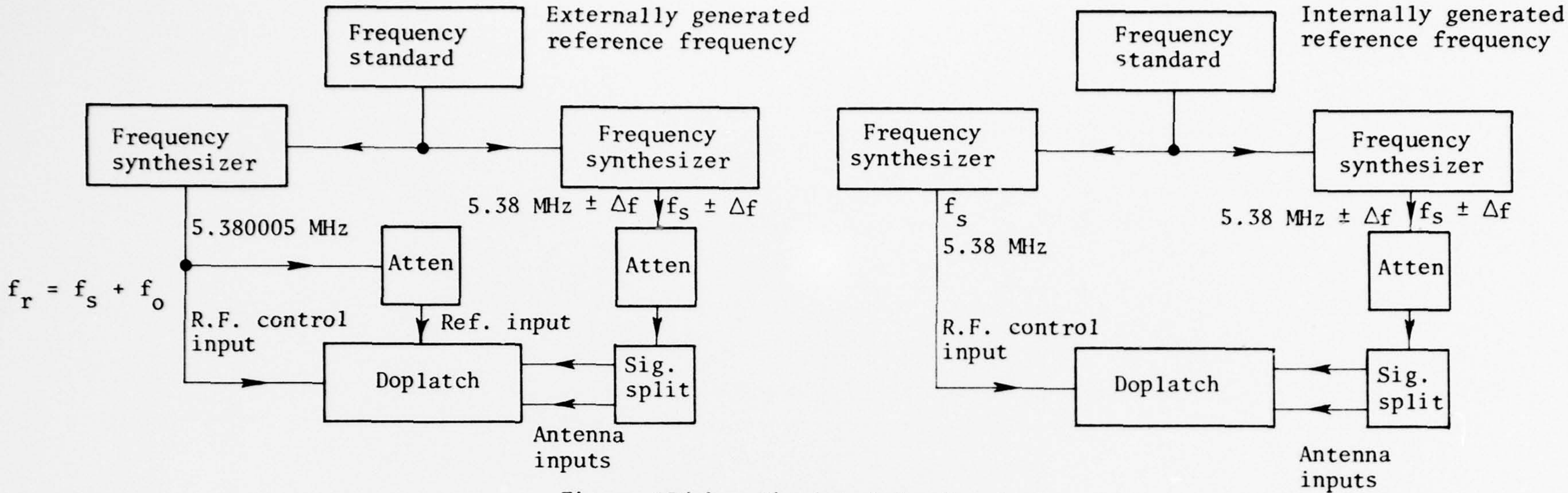


Figure 15(a). Simulated doppler tests

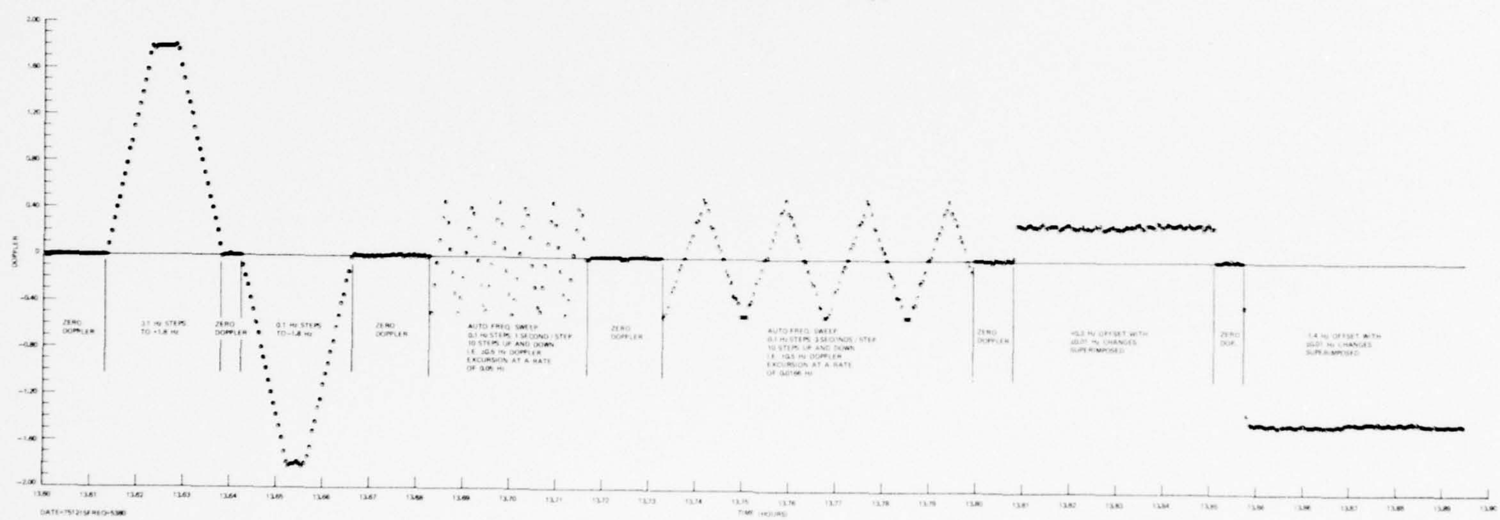


Figure 15(b). Simulated doppler results

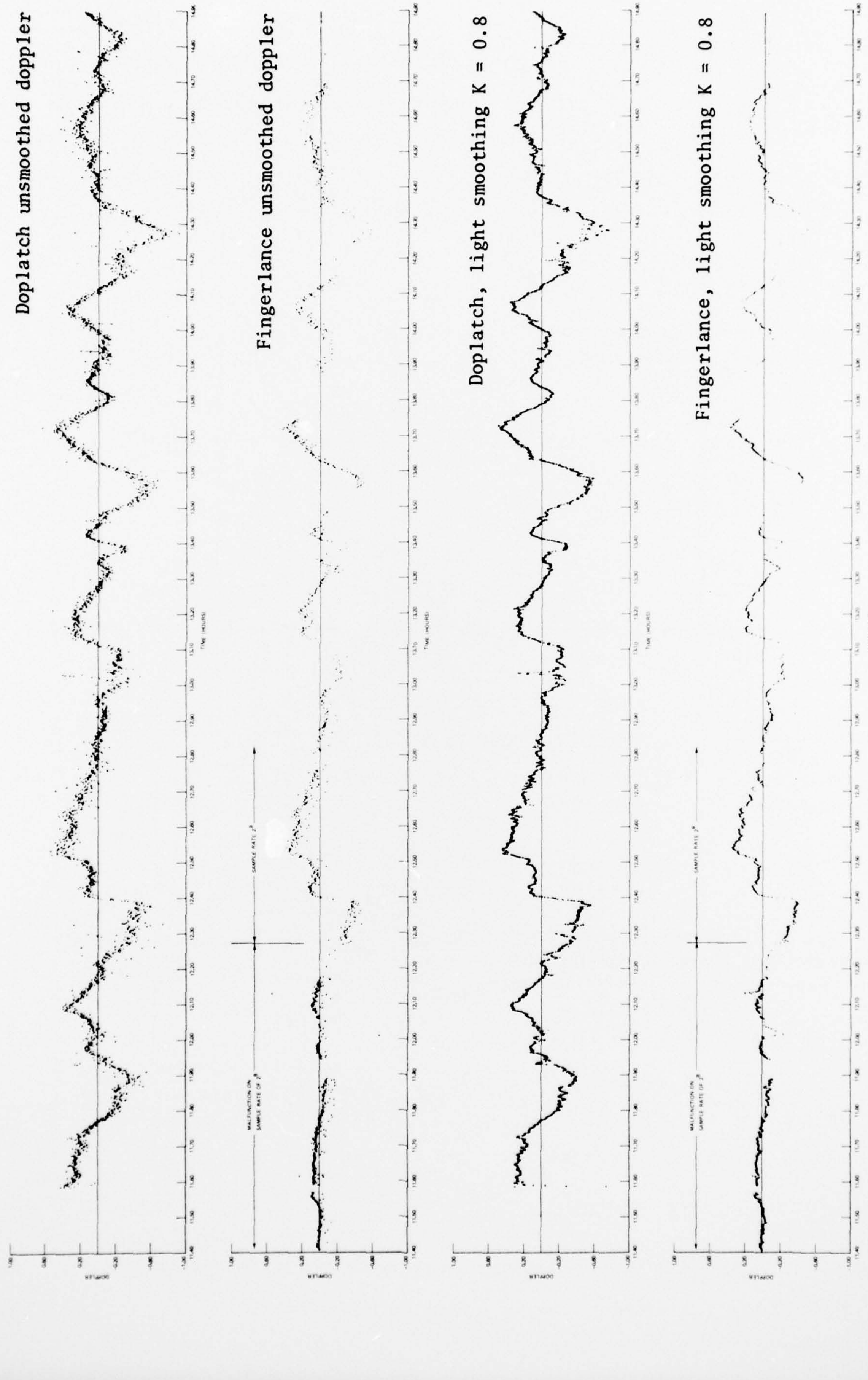


Figure 16. Doppler data comparison between doplatch and fingerlance

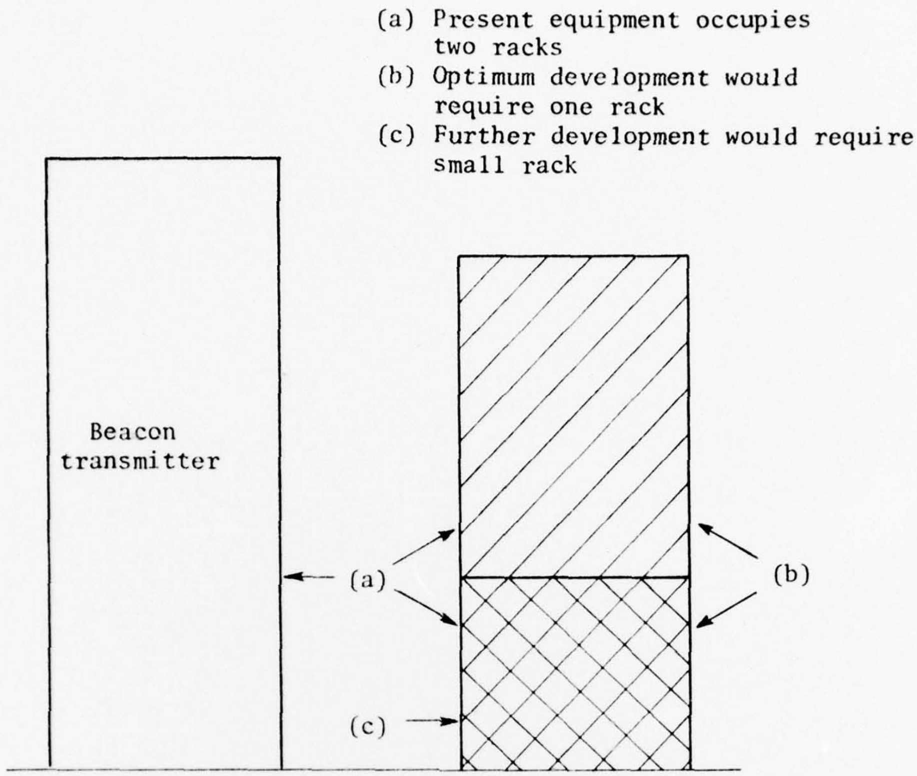


Figure 17. Showing reduction of equipment bulk possible with further development

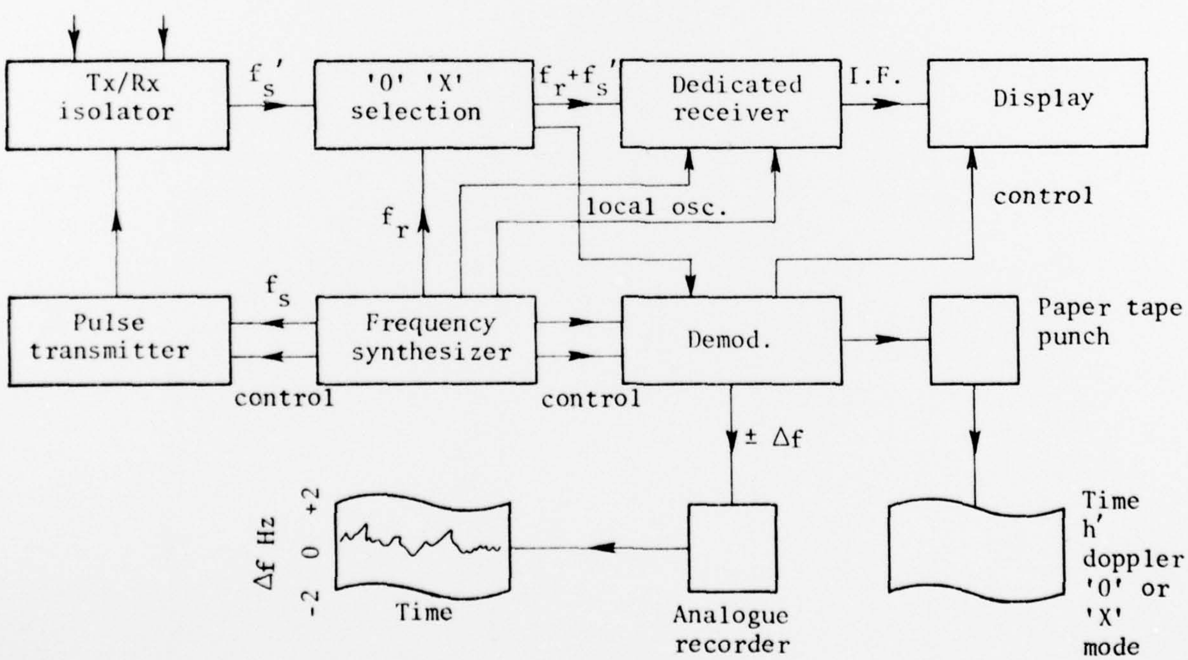


Figure 18. Basic block schematic with dedicated receiver

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